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CO-Principal Investigator: Chris Peterson

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

Over the course of this project we developed a mathematical representation of data, which we refer to as data bundles. This approach provides a mechanism for encoding the data including aspects of the signal that might normally be removed to simplify data processing. Motivated by the mathematics of fiber bundles, a data bundle provides a flexible representation of information that embraces variations that one would normally attempt to limit, or exclude entirely. Such an approach motivates the idea of intelligent data acquisition wherein the state of an object may actually be varied to enrich the data collection process.

The data bundle is a natural way to encode information which can then be viewed as a point on a variety of parameter spaces such as Grassmann manifolds, Flag manifolds, or Stiefel manifolds. Each setting provides a different view of the data and similarity measures may be constructed in these settings to optimize discriminatory strength of any classification system. The development of the basic mathematical theory of data bundles into practical algorithms will bring fundamentally new tools to bear on the problem of processing large quantities of streaming data.

15. SUBJECT TERMS

Standard terms apply

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Classification of Data Bundles via Parameter Spaces

AFOSR grant DOD/AFOSR FA9550-08-1-0166
Final Report Period 3/1/2008-5/31/2011
Principal Investigator: Michael Kirby
CO-Principal Investigator: Chris Peterson
Department of Mathematics
Colorado State University, Fort Collins, CO 80523.

December 1, 2011

1 Objectives

Over the course of this project we developed a mathematical representation of data, which we refer to as data bundles. This approach provides a mechanism for encoding the data including aspects of the signal that might normally be removed to simplify data processing. Motivated by the mathematics of fiber bundles, a data bundle provides a flexible representation of information that embraces variations that one would normally attempt to limit, or exclude entirely. Such an approach motivates the idea of intelligent data acquisition wherein the state of an object may actually be varied to enrich the data collection process.

The data bundle is a natural way to encode information which can then be viewed as a point on a variety of parameter spaces such as Grassmann manifolds, Flag manifolds, or Stiefel manifolds. Each setting provides a different *view* of the data and similarity measures may be constructed in these settings to optimize discriminatory strength of any classification system. The development of the basic mathematical theory of data bundles into practical algorithms will bring fundamentally new tools to bear on the problem of processing large quantities of streaming data.

2 Accomplishments

Over the time period of this award three students received their Ph.D.s and three students earned Masters degrees. Seventeen papers appeared in publication and 16 presentations were given, the majority of them invited. Basic algorithms have been developed and applied to, e.g., data cubes arising in video streams and hyperspectral imagery. The results of this research continue to

be applied and further extended in a number of directions. For example, the DARPA "Mind's Eye" project *Visual Intelligence through Latent Geometry and Selective Guidance*, uses elements of these ideas as part of a system for mapping video data to text. The NSF program "Algorithms for Threat Detection" is supporting further work for exploiting the algorithms developed here for the detection of biological and chemical agents. Further details on these and additional transitions is provided in Section 5.2 of this report.

2.1 Student Mentoring

Ph.D. students awarded degrees:

- Elly Smith, Ph.D., 2010
- Arta Jamshidi, Ph.D., Summer 2008
- Jen-Mei Chang, Ph.D., Spring 2008

Masters students awarded degrees:

- Justin Marks, (currently qualified Ph.D. student, CSU)
- Lori Ziegelmeier, (currently qualified Ph.D. student, CSU)
- Tim McCoy, (currently Ph.D. student University of Notre Dame)

Arta Jamshidi was hired as a Postdoctoral research associate at Princeton Univeristy. Jen-Mei Chang was hired as a tenure track assistant professor at California State University, Long Beach. Elly Smith was hired as a tenure track assistant professor at Kenyon College.

3 Personnel Supported

Michael Kirby, PI. Chris Peterson, CO-PI.

4 Technical Publications

1. A. Jamshidi, M. Kirby and D. Broomhead, *Geometric Manifold learning using dimension reduction and skew radial basis functions*, to appear IEEE Magazine on Signal Processing, Special Issue on Dimensionality Reduction via Subspace and Manifold Learning, Vol 28, No. 2, March 2011.
2. D. Bates, J. Hauenstein, C. Peterson, A. Sommese, *Numerical decomposition of the rank-deficiency set of a polynomial matrix*, Approximate Commutative Algebra, L. Robbiano and J. Abbott (eds.), Texts and Monographs in Symbolic Computation, Springer-Verlag, Vienna (2010)

3. A. Jamshidi and M. Kirby, *Modeling Multivariate Time-Series on Manifolds with Skew Radial Basis Functions*, Neural Comput. 2011 Jan;23(1):97-123. Epub 2010 Oct 21, 2010.

4. D. Elliott, C.W. Anderson and M. Kirby (2010), *Covariance Regularization for Supervised Learning in High Dimensions*, Proceedings of ANNIE 2010.

5. Josh Thompson, David W. Dreisigmeyer, Terry Jones, Michael Kirby, and Josh Ladd (2010), *Accurate Fault Prediction of BlueGene/P RAS Logs Via Geometric Methods*, Proceedings 1st Workshop on Fault-Tolerance for HPC at Extreme Scale (FTXS 2010) , Chicago, Illinois.

6. Yui Man Lui, J. Ross Beveridge and Michael Kirby (2010), *Action Classification on Product Manifolds*, IEEE Conference on Computer Vision and Pattern Recognition.

7. A. Jamshidi and M. Kirby (2010), *Skew-Radial Basis Function Expansions for Empirical Modeling*, SIAM J. Sci. Comput. Volume 31, Issue 6, pp. 4715–4743.

8. Yui Man Lui, J. Ross Beveridge and Michael Kirby (2009), Canonical Stiefel Quotient and its Application to Illumination Spaces, IEEE International Conference on Biometrics: Theory, Applications and Systems. (Oral presentation acceptance rate 20%; received best paper award).

9. H. Abo, G. Ottaviani and C. Peterson, *Induction for secant varieties of Segre varieties*, Trans. Amer. Math. Soc. Vol. 361 Number 2, pg. 767-792 (2009)

10. J.R. Beveridge, Bruce Draper, Jen-Mei Chang, Michael Kirby, Holger Kley and Chris Peterson (2009), *Principal Angles Separate Subject Illumination Spaces in YDB and CMU-PIE*, IEEE Trans. on Pattern Analysis and Machine Intelligence, Vol. 31, No. 2, pp 351-363.

11. J. Hauenstein, J. Migliore, C. Peterson, A. Sommese, *Numerical Computation of the Dimension of the Cohomology of Twists of Ideal Sheaves*, To appear: Interactions of Classical and Numerical Algebraic Geometry, D. Bates, G. Besana, S. Di Rocco, and C. Wampler (eds.), Contemporary Mathematics (2009)

12. D. Bates, J. Hauenstein, C. Peterson, A. Sommese, *A local Dimension Test*, SIAM J. Numer. Anal. Volume 47, Issue 5, pp. 3608-3623 (2009)

13. A. Jamshidi and M. Kirby, *Skew-Radial Basis Functions for Modeling Edges and Jumps*, To appear in: Eighth International Conference on Mathematics in Signal Processing Conference Digest, The Royal Agricultural College, Cirencester, Institute for Mathematics and its Applications, December, 2008.

14. Yui Man Lui, J. Ross Beveridge, Bruce A. Draper and Michael Kirby, *Image-Set Matching using a Geodesic Distance and Cohort Normalization*, IEEE International Conference on Automatic Face and Gesture Recognition, Amsterdam, The Netherlands, 2008

15. Fatemeh Emdad, Michael Kirby, and Seyed A. Zekavat, *Feature Extraction via Kernelized Signal Fraction Analysis vs Kernelized Principal Component Analysis*, in proceedings, World Comp Congress 08, Data Mining Symposium, Las Vegas, July 2008.

16. E. Smith and C. Peterson, *Geometric properties of locally minimal energy configurations of points on spheres and special orthogonal groups*, To appear in *Proceedings of Milestones in Computer Algebra MICA 2008: A conference in honour of Keith Geddes' 60th birthday*, Marc Moreno Maza and Stephen M. Watt (editors), University of Western Ontario, 2008, ISBN 978-1-59593-744-5.

17. C. Frederick and C. Peterson, *Ramsey Regions*, Discrete Mathematics Vol. 308 (18) pg 4079-4085 (2008)

5 Interactions/Transitions

5.1 Presentations

Over the course of last year three presentations of the results of this project were made. The PI made the following presentations:

1. *Geometry and the Analysis of Massive Data Sets*, Workshop on Manifold Learning, Hausdorff Research Institute for Mathematics, Bonn, Germany 5/2011, (Invited).

2. *Some geometric approaches for analyzing data cubes*, A Meeting in Honour of Dave Broomhead's 60th Birthday, University of Manchester, 11/2010 (Invited)

3. *Petascale Data Analysis*, Sandia National Labs, 5/2009. (Invited)

4. *Opportunities for Extreme Data Analysis*, Oakridge National Labs 2/27/09. (Invited.)

5. *Optimizing Detection Characterization and Classification of Features and Anomolies in Signals*, Directorate for Central Intelligence Postdoctoral Fellow Colloquium, Chantilly VA, 2009.

6. *New Algorithms for Analyzing Large Data Sets*, National Science Foundation Workshop: Algorithms 2008, Baltimore, November 2008. (Invited.)

The CO-PI made the following presentations:

1. Stanford - one of 6 talks at Bay Area Discrete Math conference (Sept 2008)
2. Washington DC - AMS meeting - talk (Jan 2009)
3. North Carolina - AMS Meeting - talk (April 2009)
4. Nice, France - Tensors Workshop (June 2009)
5. Raleigh, North Carolina - AMS Meeting - talk (April 2009)
6. Lincoln, Nebraska - KUMUNU 2009 - talk (September 2009)
7. Palo Alto, California - AIM Workshop - Implementing algebraic geometry algorithms (October 2009)
8. 10 hour course on Algebraic Geometry at U. of Costa Rica (Feb 1-14 2010)
9. San Jose, Costa Rica - Research talk at the University of Costa Rica (February 2010)
10. Dandryd, Sweden - Institute Mittag-Leffler (May 2011)

5.2 Transitions

Related activities that benefit from this effort.

1. CO-Principal Investigator, *Visual Intelligence through Latent Geometry and Selective Guidance*, Defense Advance Research Projects Agency $ 627,215, 6/23/2010-6/22/2015.
2. *ATD: Mathematical Algorithms for Characterizing Spectral Signatures*, National Science Foundation, $401,712, 9/1/09-8/31/12.
3. *Optimizing Detection, Characterization, and Classification of Features and Anomalies in Signals*, DOD-NGA-Natl Geospatial-Intelligence, $239,700, 9/10/08-9/9/10.
4. *CMG: Analysis of Transport, Mixing, and Coherent Structures in Hurricane Intensity*, NSF ATM-530884, Funding 10/1/05–9/30/09.

6 Patent Disclosures

None.